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The Potential of Commercial Biomass-Based Activated Carbon to Remove Heavy Metals in Wastewater – A Review

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ABSTRAK

Karbon aktif komersial ialah jenis adsorbent yang sering digunakan dalam proses adsorpsi. Namun, penggunaan dari karbon komersial dalam pengolahan air limbah dibatasi, karena terbatasnya ketersediaan prekusor dan harganya cukup mahal. Biomassa sebagai prekusor karbon aktif telah dilaporkan memiliki efisiensi yang tinggi dalam menghilangkan berbagai macam logam berat dalam air limbah. Penelitian ini bertujuan untuk meninjau potensi karbon aktif berbasis biomassa untuk mengadsorpsi logam berat dalam hal komponen penyusun biomassa, penyisihan logam berat, dan prospek di masa depan. Metode dalam penelitian yaitu tinjauan literatur sistematis, atau SLR, untuk mengumpulkan data dari database online seperti Google Scholar, PubMed, dan ScienceDirect. Hasil penelitian menunjukkan bahwa karbon aktif berbasis biomassa efektif dalam menyisihkan logam berat dalam berbagai jenis air limbah. Efektivitas penyisihan untuk berbagai jenis biomassa berkisar antara 84–99% untuk ion Pb^{2+}, 55–92% untuk ion Cd^{2+}, 84–99% untuk ion Pb^{2+}, 96% untuk ion As^{2+}, 80–100% untuk ion Cr^{2+}, 25–97% untuk ion Fe^{2+}, 50–99% untuk ion Ni^{2+}, dan 62–98% untuk ion Cu^{2+}, serta 98% untuk ion Ti. Hasil ini menunjukkan bahwa logam berat memiliki afinitas yang berbeda-beda terhadap karbon aktif dari biomassa, dari semua logam berat, ion Fe^{2+} dan Cd^{2+} memiliki afinitas yang terendah, sehingga karbon aktif yang digunakan untuk menghilangkan logam Fe^{2+} dan Cd^{2+} perlu diproduksi dengan porositas dan luas permukaan yang lebih tinggi. Penyisihan logam berat menggunakan karbon aktif dari biomassa dibatasi oleh dosis adsorbent waktu kontak, pH larutan, temperatur, konsentrasi awal adsorbat, ukuran partikel dan kecepatan pengadukan. Pada penelitian selanjutnya diharapkan adanya karbon aktif dari biomassa yang mempunyai kapasitas adsorpsi tinggi, ekonomis, ramah lingkungan dan dapat digunakan dalam skala luas.

Kata kunci: Karbon aktif, Biomassa, Logam berat, Lignoselulosa, Pengolahan air limbah.

ABSTRACT

Commercial activated carbon is a type of adsorbent commonly used in adsorption processes. However, the use of commercial carbon in wastewater treatment is still limited, due to the scarce availability of precursors and their high cost. Biomass as an activated carbon precursor has been reported to have high efficiency in removing various heavy metals in wastewater. This study aims to review the potential of biomass-based activated carbon to adsorb heavy metals in terms of biomass constituent components, heavy metal removal, and future prospects. The method in this study is a systematic literature review, or SLR, to collect data from online databases such as Google Scholar, PubMed, and ScienceDirect. The results show that biomass-based activated carbon is effective in the removal of heavy metals in various types of wastewater. The removal effectiveness for different types of biomass ranged from 84–99% for Pb^{2+} ions, 55–92% for Cd^{2+} ions, 84–99% for Pb^{2+} ions, 96% for As^{2+} ions, 80–100% for Cr^{2+} ions, 25–97% for Fe^{2+} ions, 50–99% for Ni^{2+} ions, and 62–98% for Cu^{2+} ions, and 98% for Ti ions. These results show that heavy metals have different affinities to activated carbon from biomass, from all heavy metals, Fe^{2+} and Cd^{2+} ions have the lowest affinity, so the activated carbon used to remove Fe^{2+} and Cd^{2+} metals needs to be produced with higher porosity and surface area. The removal of heavy metals using activated carbon from biomass is limited by adsorbent dosage, contact time, solution pH, temperature, initial adsorbate concentration, particle size, and stirring speed. In future research, it is expected that activated carbon from biomass has a high adsorption capacity, is economical cost, is environmentally friendly, and can be used on a larger scale.

Keywords: Activated carbon, Biomass, Heavy metals, Lignocellulose, Wastewater treatment.

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1. Introduction

Heavy metals are pollutants produced by various industries, including the textile, dyeing, batteries, leather, fertilizer, chemical, mining, metallurgy, and refinery. The heavy metals such as Cd, Cu, Zn, Pb, Fe, Hg, Ni, Mn, and Co are commonly found in small concentrations of industrial wastewater but are considered elements harmful to living beings (Zhou et al., 2020), as these metals are not biodegradable and highly toxic. Metals adsorbed and accumulated in the human body can cause cancer, tumours, brain diseases, psychiatric diseases, sexual diseases and so on (Shafiq et al., 2018).

Various materials are offered as adsorbents, but activated carbon is an accepted material for removing pollutants in wastewater. In removing heavy metals from wastewater, activated carbon has long been recognized as the best adsorbent in the industry (Lu et al., 2014). Applying the adsorption method with activated carbon was chosen because it is relatively easy. Compared to other adsorbents, activated carbon has a very high surface area and capacity for adsorption, making its use more optimal (Gunawan et al., 2020). Several different carbonaceous materials can be used to make activated carbon, but until recently, the primary sources of commercial carbon were coal, anthracite, and bitumen (Saleem et al., 2019).

The precursor materials of commercial activated carbon, such as petroleum waste, coal, asphalt, and lignite used in commercial activated carbon production, are expensive and non-renewable (Yahya et al., 2015). The availability of such precursors is limited (Elavarasan, 2018), and the cost required for commercial activated carbon regeneration is expensive (Ali et al., 2012). High production costs and expensive materials limit their use in wastewater treatment. Alternatively, locally available, abundant in nature and renewable materials, such as biomass, can be modified physically and chemically as activated carbon (Azmi et al., 2014). Biomass is a term for waste material from plants, animals, and other organic substances. Biomass is a non-lignocellulose or lignocellulose material that comes in many shapes and sizes, including wood, herbs, aquatic detritus, manure and byproducts, and other forms (Osman et al., 2019).

Lignocellulose biomass has gained significant attention as the only abundant renewable energy source with many ecological benefits (Bu et al., 2015).

Lignocellulose biomass is made from photosynthesis of various types of land plants or aquatic plants (Long et al., 2013). Lignocellulosic biomass is the ideal feedstock for making activated carbon as it is the only renewable source of green carbon. In addition, lignocellulose biomass also has high adsorption capacity, simple regeneration, abundant availability, low cost, and reduced disposal problems after adsorption (Khatoon & Rai, 2016). Therefore, lignocellulose biomass affordable, and sustainable alternative to manufacture activated carbon. In addition, biomass-based activated carbon can be adapted for various purposes (Pallarés et al., 2018). The advantages and disadvantages of commercial and biomass-based activated carbon are present in Table 1. Biomass-based activated carbon has many advantages over commercial carbon. However, recent studies have shown that the activation of biomass-based activated carbon uses large acid doses (Kolur et al., 2019). So, the effluent from the activated carbon treatment will contaminate the sewer system and stop the hydrolysis process in the environment (Bakar et al., 2021).

Many researchers have utilized lignocellulose biomass as activated carbon to remove heavy metals in wastewater. The biomass includes banana peels (Ajmi et al., 2018), soybean seeds (Gaur et al., 2018), neem leaves (Pournima & Shrikant, 2018), olive seeds and palm seeds (Obregón-Valencia & Sun-Kou, 2014), and Leucaena leucocephala seed pods (Yusuff, 2019). Therefore, this study aims to review the potential of biomass-based activated carbon to adsorb heavy metals in terms of biomass constituent components, heavy metal removal, and future prospects.

2. Method

The method in this study is a systematic literature review or also known as Systematic Literature Review (SLR). SLR is a literature review that refers to a certain set of standard rules for identifying and synthesizing all related previous literature, as well as assessing important things about the topic under study (Xiao & Watson, 2019). Through SLR, a more informative research summary or synthesis will be obtained as well as a comprehensive research critique. The SLR method in this study was carried out by searching various scientific articles through electronic databases, such as Google Scholar, PubMed, and ScienceDirect. The keyword used in the search was "Activated carbon from lignocellulose biomass for heavy metal removal in wastewater".

The search results were then filtered by title and abstract. Additional rules were also used in the selection of research works for detailed analysis, which included 1) Publications on activated carbon, plant biomass, heavy metals, and wastewater treatment; 2) Publication of works within the last ten years, between 2013 and 2023; 3) Publications in internationally reputed journals; 4) Easily accessible full journal text. Only eligible articles were included in this review. The article screening process is presented in Figure 1.

Table 1. Advantages and disadvantages of commercial and biomass-based activated carbon

Activated Carbon	Advantages	Disadvantages
Commercial	• Easy to find • High adsorption capacity	• Limited precursor availability • High price (271 US $) • The cost of regeneration is expensive
Biomass	• High adsorption capacity (22-277 mg.g^{-1}) • Abundant precursor availability • Economical cost (42 US $) • Easy regeneration • Less disposal problems after adsorption	• Acidic waste from activated carbon activation causes contamination of drainage systems and disrupts biodegradation cycles.

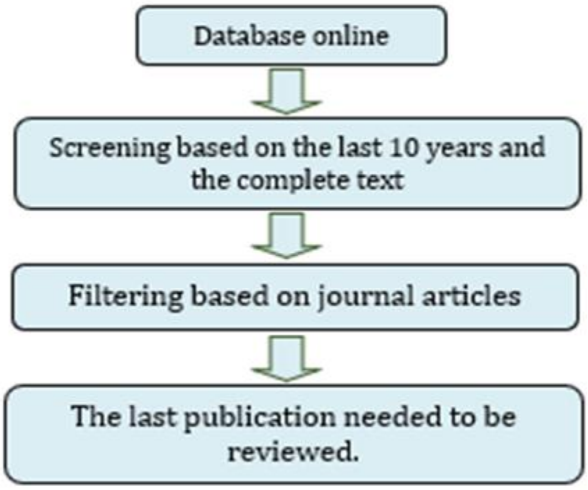

Figure 1. Diagram of article screening

3. Result and Discussions

3.1. Biomass-Based Activated Carbon

3.1.1. Constituent Components of Biomass-Based Activated Carbon

Amorphous materials are called activated carbons, usually containing a well-organized tissue of pores with a high proportion of micro or mesopores structural. Due to its naturally connected pore network, lignocellulosic biomass is a highly applicable precursor for producing porous activated carbon (Dutta et al., 2014). Lignocellulose biomass has hollow holes and plates connecting vertical and horizontal pores. This network of pores plays an essential role in transferring plant nutrients so that they can transport anorganic ions and nutritional components (Jiang et al., 2020).

According to (Karaboyaci et al., 2017), lignocellulose biomass comprises three main components: lignin, cellulose, and hemicellulose. The structural elements constituent of lignocellulose biomass is illustrateds in Figure 2. Lignin is essential in absorbing heavy metals from raw or unaltered lignocellulose biomass. Escudero-Oñate et al. (2017) state that lignin is crucial for adsorption because it supplies polyphenol and polyhydroxy functional elements that are helpful for heavy metal coordination and promote ion exchange activity in materials. It is also part of the lignocellulose biomass that is most thermally stable. Due to these properties, lignin-rich biomass is suitable for producing the best-activated carbon.

According to Escudero-Oñate et al. (2017), adsorbents of lignocellulose have a proportion of 30–35% cellulose, 20–40% hemicellulose and 15–25% lignin. The ash, waters, cyclic hydro-carbons, and extractive are other micro-components. According to Kayranli et al. (2021), the banana peel contains lignin 16.45%, cellulose 18.06%, hemicellulose 21.40%, crude protein 1.4%, fibre 10.56%, and ash 4.5%. Sugar bagasse's lignocellulose composition is 36.78% cellulose, 26.04% hemicellulose, 10.51% lignin, and 26.67% ash (Arni, 2018). Rice husks are composed of cellulose 35%, hemicellulose 25%, lignin 20%, and ash 17% (Ma'ruf et al., 2017).

Watermelon peel contains lignin 6–8.63%, cellulose 52.27% and hemicellulose 10.14–19.51% (Fakayode et al., 2021). Potato peels contain 39.36% cellulose components, 13.11% lignin, 9.04% hemicellulose, and 2.31% pectin (Zhu et al., 2023). 75-90% of rice husk biomass is organic matter (cellulose and lignin), while 10-25% is organic (Carmona et al., 2013). Adsorbents from chemically treated biomass have a much greater adsorption ability than non-treated adsorbents (Ali et al., 2016). Adsorbents from chemically treated biomass have a much greater adsorption ability than non-treated adsorbents. According to (Pournima & Shrikant, 2018), Cu metal can be removed from wastewater by silica, cellulose, lignin, carbohydrate, and other biomass components. Biomass offers many benefits, such as a cheap feedstock to replace commercial carbon and as a problem-solving component for removing heavy metals from wastewater.

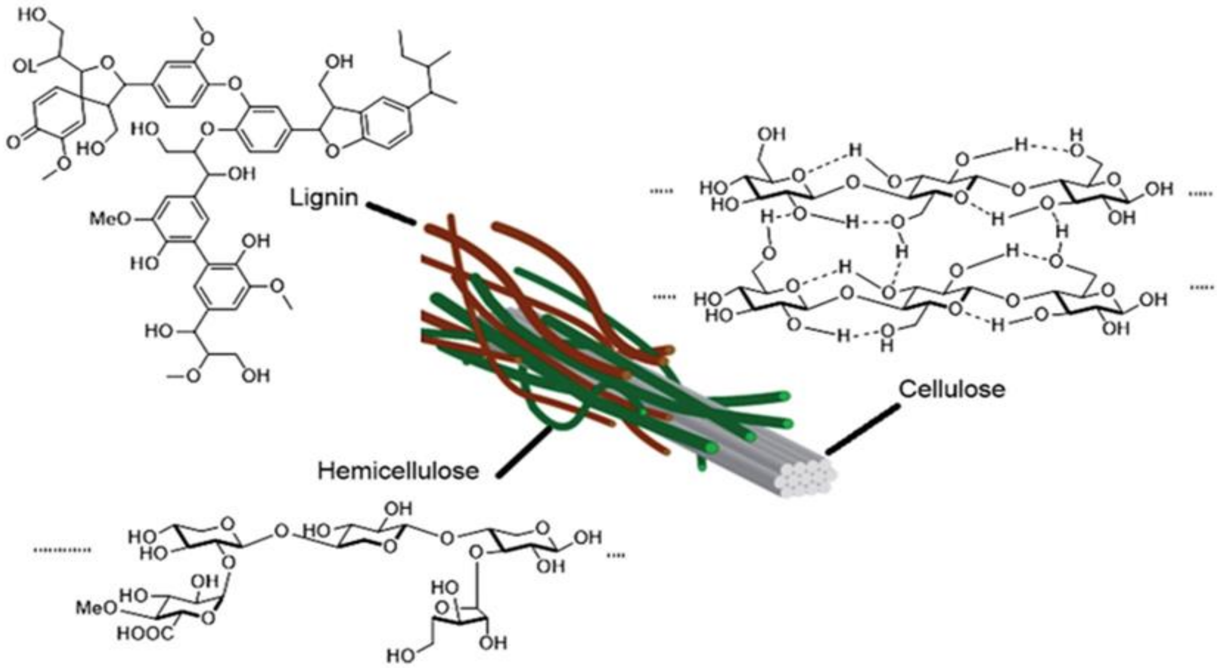

Figure 2. Structural elements of lignocellulose biomass (Li & Takkellapati, 2018)

3.1.2. Biomass-Based Activated Carbon Applications

Lignocellulosic biomass has a high potential as an activated carbon precursor. Biomass-based activated carbon can adsorb various heavy metals in wastewater. Biomass-based activated carbon has been applied in various experiments to remove metal contaminants easily and cheaply(Burakov et al., 2018). Table 2 details the use of activated carbon derived from several types of biomass for wastewater treatment.

Based on the summary in Table 2, activated carbon based on lignocellulosic biomass can remove different heavy metals in wastewater. The biomass derived from several plant parts reportedly can be used as an activated carbon precursor. Previous experiments have reported the removal of heavy metals by plant biomass, such as leaves, stems, seeds, and fruit peels. Lead metal (Pb) can be reduced using activated carbon from aloe vera leaves, bamboo stems, corn cobs, cherry seeds, apricot shells, potato peels, and banana peels, with an effectiveness of 84-99%. The significance of removing cadmium (Cd) with activated carbon from bamboo stems, olive seeds and palms, and banana peels was 55-98%. Activated carbon from bamboo sticks can remove arsenic (As) from oil and gas industry wastewater with an effectiveness of 96% (Thotagamuge et al., 2021). Chromium (Cr) metal from various wastewater types can remove by activated carbon from bamboo stems, rice straws, black sapote seeds, apricot fruit peels, banana peels, and rice husks with an effectiveness of 80-100%. Removal of iron (Fe) from wastewater with activated carbon from bamboo stems, bagasse, black sapote seeds, and apricot shells, the effectiveness ranged from 25-97%. Nickel (Ni) can remove by activated carbon from bamboo stems, cherry seeds, rice husks and orange peels with an effectiveness of 50-99%. 89% of the zinc (Zn) metal was successfully removed from textile effluent using sugarcane bagasse-derived activated carbon (Razi et al., 2018). Copper (Cu) in wastewater can be removed by activated carbon from black sapote seeds, apricot shells, watermelon peels, rice husks and orange peels, with an effectiveness of 62-99%. Meanwhile, titanium (Ti) metal in wastewater can be removed with watermelon peel-activated carbon with 98% effectiveness (Li et al., 2019). According to Vukelic et al. (2018), commercial activated carbon can remove 87% nickel metal, 84% cadmium and 74% lead in wastewater. In a study by Thotagamuge et al. (2021), commercial activated carbon can remove 58% Cu, 15% Cd, Pb, and Cr, 10% As and Ni in wastewater from the oil and gas industry. These results indicate that the removal efficiency of heavy metals in wastewater with plant biomass-based activated carbon (lignocellulose) is equal to or even higher than commercial activated carbon. Thus, biomass is a potential precursor as activated carbon for heavy metal removal in wastewater.

3.2. Limiting Factors

3.2.1. Adsorbent Dosage

The quantity of adsorbent used in removing heavy metal is significant because it determines the balance between absorbent materials and contaminants, which estimates the adsorption price for each unit of solution (Mohamed et al., 2019). The number of heavy metal ions adsorbed usually increases with increased adsorbent dosage up to a certain point before becoming constant. This result indicates that maximum adsorption will occur at a given adsorbent dose for each concentration of metal ions (Soliman & Moustafa, 2020).

Table 2. Wastewater treatment using activated carbon from biomass.

Part of plant	Biomass	Types of wastewater	Heavy metals	Effectiveness	Reference
Leaf	Aloe Vera Leaf	Wastewater	Pb^{2+}	96%	Malik et al. (2015)
Stems	Bamboo sticks	Oil and gas industry wastewater	Cd^{2+}	55%	Thotagamuge et al. (2021)
			Pb^{2+}	96%	
			As^{2+}	96%	
			Cr^{2+}	96%	
			Fe^{2+}	25%	
			Ni^{2+}	50%	
	Rice straw	Wastewater	Cr^{2+}	97%	Kumar & Jena (2017)
	Sugar bagasse	Wastewater Textile industry	Fe^{2+}	91%	Razi et al. (2018)
			Zn^{2+}	89%	
Fruit	Corn cobs	Wastewater Leather industry	Pb^{2+}	95%	Muthusamy & Murugan (2016)
Seed	Black sapote seeds	Mining wastewater	Cr^{2+}	100%	Peláez-Cid et al. (2020)
			Cu^{2+}	98%	
			Fe^{2+}	96%	
			Pb^{2+}	99%	
	Apricot shell	Wastewater	Fe^{2+}	97%	Šoštarić et al. (2018)
			Pb^{2+}	87%	
			Cu^{2+}	81%	
			Cr^{2+}	80%	
	Cherry seeds	Wastewater	Pb^{2+}	94%	Vukelic et al. (2018)
			Cd^{2+}	92%	
			Ni^{2+}	66%	
	Olive seeds	Wastewater	Cd^{2+}	68%	Obregón-Valencia & Sun-Kou (2014)
	Palm seeds		Cd^{2+}	55%	
Peels	Banana peels	Battery and power industry wastewater	Cd^{2+}	98%	Ajmi et al. (2018)
			Cr^{2+}	99%	
			Pb^{2+}	97%	
	Potato peels	Wastewater	Pb^{2+}	84%	Osman et al. (2019)
	Watermelon peel	Wastewater	Ti	98%	Li et al. (2019)
	Watermelon peel	Wastewater	Cu^{2+}	98%	Gupta & Gogate (2016)
	Rice husks	Synthetic wastewater	Cu^{2+}	62%	Naik et al. (2023)
			Ni^{2+}	65%	
	Rice husks and orange peels		Cu^{2+}	99%	
			Ni^{2+}	99%	
	Rice husks	Tannery Wastewater	Cr^{2+}	99%	Vunain et al. (2021)

The increase in adsorbent dosage significantly increases active sites, surface area, and the number of metal ions adsorbed. For example, (Kumar & Jena, 2017) investigated the impact of the adsorbent dosage on removing Cr(VI)using peanut shell activated carbon (Fig. 3). The percentage removal of Cr(VI) increased sharply by increasing the dose of adsorbent until 0.04 g before constant. Meanwhile, according to Özsin et al. (2019), the removal of adsorbed metals decreased as the dose of carbon increased. The adsorbent dose of lead (Pb) and chromium (Cr) were found to be optimal at 2 g/L, while copper (Cu) was optimal at 3 g/L.

3.2.2 Contact Time

Contact time is the period it takes for the system to reach equilibrium. Solid or liquid heterogeneous systems typically undergo various mass transfer processes, some of which may be relatively slow. With a longer contact time, the biosorption of heavy metals may increase (Khatoon dan Rai, 2016). Activated carbon made from papaya peel is used by Mittal et al. (2021) to study the impact of contact duration on the removal of Pb(II), Ni(II), and Cu(II) ions (Fig. 5).

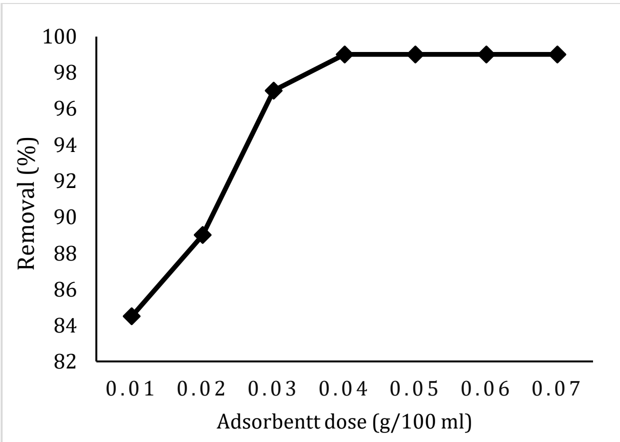

Figure 3. Impact of adsorbent dosege on Cr(VI) removal by activated carbon from peanut shell (Kumar & Jena, 2017).

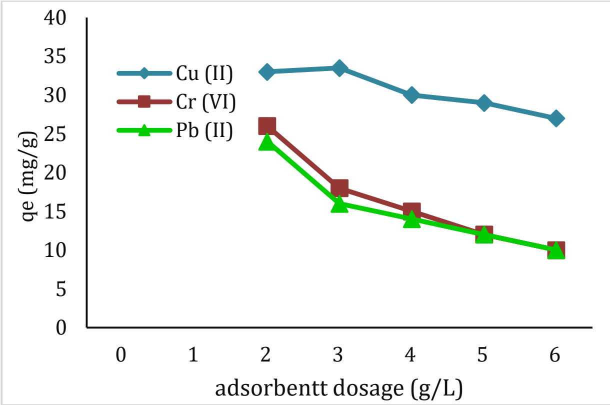

Figure 4. Impact of adsorbent dose on sorption of Pb, Cr, and Cu metal by chickpea peel activated carbon (Özsin et al., 2019)

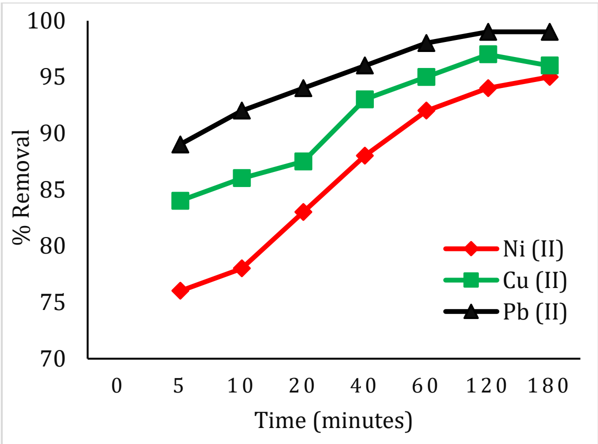

Figure 5. Impact of contact time on the metal ion sorption by papaya peel carbon (Mittal et al., 2021).

The number of heavy metal ions adsorbed over time of all three metals starts quickly but slows down with time, and no adsorption of metal ions is visible once equilibrium is reached. Metal ions can first fill the adsorption site. However, as time passes, fewer free sites become available, and the amount of unadsorbed cations in the solution increases, limiting the adsorption capacity (Bohli et al., 2015).

3.2.3 Solution pH

Solution pH significantly impacts the adsorption in heavy metals, as pH controls an adsorbent's properties, including the surface charges, specifications of the adsorbate and the ionization level in the solution (Alghamdi et al., 2019). Figure 6 illustrates more protons on the carbon surface interacting with the metal ions of the solution. When pH rises, lead (Pb), copper (Cu), and chromium (Cr) adsorption increase. Metal adsorption decreases at pH>9, possibly related to a binding or dissociation of functional groups on the surface. In addition, the change in pH of the solution from 8 to 9 does not significantly change the absorption rate (Özsin et al., 2019).

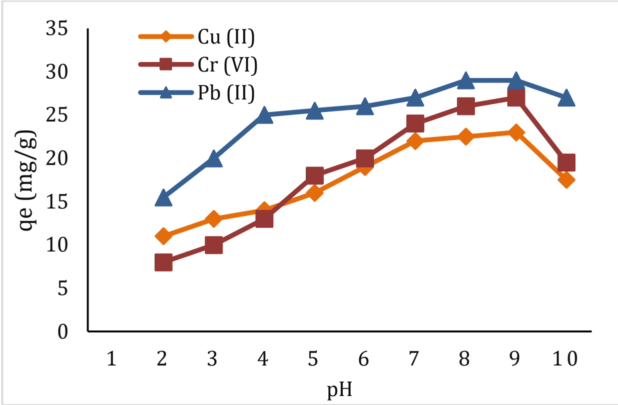

Figure 6. Impact of the solution pH on the sorption of Pb, Cr, and Cu metals (Özsin et al., 2019)

3.2.4 Temperature

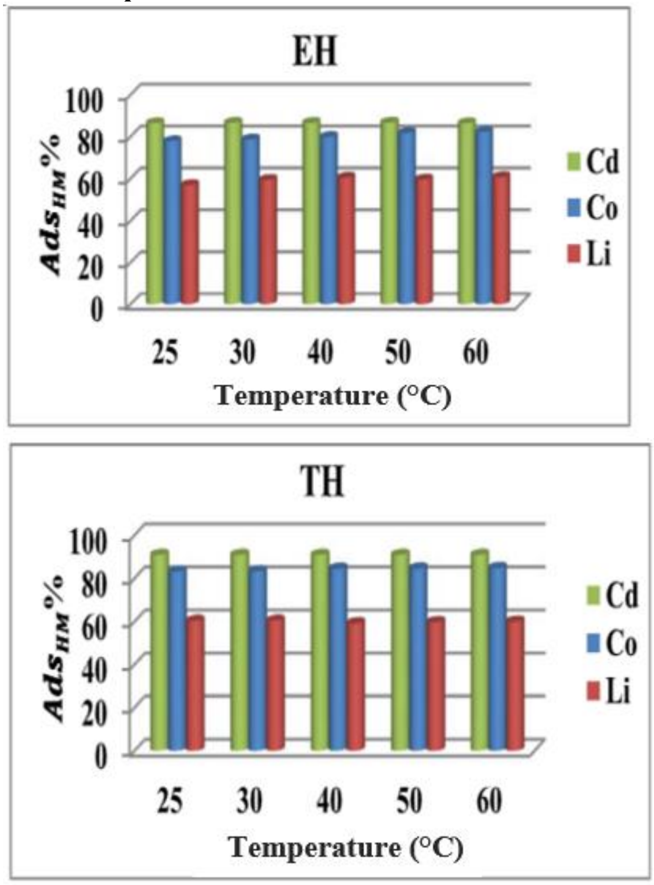

Figure 7. The impact of temperature on the removal of metal ions by *Equisetum* (EH) and Teucrium (TH) adsorbents (Al-Senani & Al-Fawzan, 2018)

Temperature can change the nature of the interaction between endothermic and exothermic systems or the reverse, which impacts adsorption (Yeow et al., 2021). The absorption efficiency is influenced by temperature, depending on the pollutants and adsorbents. Temperature can increase surface activity and adsorbate kinetic energy leading to increased biosorption of contaminants, but temperature can also damage the physical structure of biosorbents (Rápó & Tonk, 2021). Al-Senani & Al-Fawzan (2018) investigated how temperature affected the sorption of metal ions Li, Co and Cd using equisetum (EH) and Teucrium (TH) adsorbents (figure 7). The adsorption of Cd, Co, and Li metals is affected by temperatures in the range of 25-60°C. Adsorbents may absorb heavy metal ions through physical and chemical adsorption, as evidenced by the increasing adsorption with temperature variations. Mustapha et al. (2019) report that the adsorption rate reduces as the temperature rises. These results indicate that adsorption becomes negative at high temperatures (desorption).

3.2.5 Initial Adsorbate Concentration

The initial concentration of adsorbate determines the ability of the biosorbent for adsorbate uptake. The initial concentration impacts the adsorbate's absorption, which increases as the initial concentration rises. An increase in the pushing gradient force causes changes in biosorption at different adsorbate concentrations. The driving force for moving adsorbate is more potent at higher concentrations. However, the binding site will be saturated at high metal concentrations (Alkherraz et al., 2020). The adsorption sites available are filled with increasing concentrations of heavy metals, followed by decreased adsorption effectiveness. The effect of initial heavy metal concentration on metal adsorption by carbon from pine and Silver birch has been investigated by Komkiene & Baltrenaite (2016). Findings showed that the percentage of adsorption decreases with increasing initial metal concentration.

3.2.6 Particle Size/Surface Area

An adsorbent's particle size significantly impacts its ability to absorb pollutants (Al-Ghouti et al., 2017). As a result of the lower surface area, the adsorbent's increasing particle size causes a decrease in its adsorption characteristics. However, reducing the particle size of the adsorbent will increase its adsorptive properties as the surface area improves (Bohli et al., 2013). Particle size was investigated by Holliday et al. (2022), using particles measuring 200-500, 50-200, and 50 μm in adsorption. According to the findings, adsorption works best when using small particles (50 μm). Smaller particle sizes can increase the interface's ratio to volume and the number of accessible adsorption sites.

3.2.7 Speed of Agitation

Agitation is a crucial factor in adsorption because agitation allows the adsorbent to overcome the mass transfer resistance of the boundary layer (Khatoon & Rai, 2016). Increased agitation speed facilitates the mass transfer and transport of contaminated molecules. The increased surface contact promotes faster equilibration and more significant adsorption. The solids will sink to the bottom of the solution without agitation, decreasing the potential number of sites for absorption (Holliday et al., 2022). The effect of agitation speed towards metal ions removal from solution was investigated in the study Salih et al. (2021), using 100, 150 and 200 rpm speeds. Studies show that when the agitation speed increases, the effectiveness of metal removal also rises.

3.3. Future Perspective

Many studies have highlighted the potential of using lignocellulosic biomass as an activated carbon precursor to treat heavy metals from wastewater. Activated carbon made from biomass-based lignocellulose can be utilized commercially as an alternative to carbon in the future due to the abundant availability of precursors, economical price and high adsorption capacity. Therefore, further research should focus on filling the following gaps:

1) Further studies are needed to characterize activated carbons from lignocellulose biomass with the highest heavy metal absorption capacity to encourage the large-scale use of biomass-based activated carbons.
2) Various pre-processing techniques must be explored to make activated carbon efficient during heavy metal remediation.
3) Chemical activation processes have been widely used to manufacture biomass-based activated carbon. Although it produces quality activated carbon, it produces acidic wastewater that can pollute the environment. Future carbon-based biomass activation requires improvement not to produce byproducts that negatively impact the environment.
4) Despite the many studies conducted regarding the production of various biomasses as activated carbon, a more profound and more extensive range of carbon synthesis and modification methodologies is still needed, mainly focusing on each more specific type of biomass.
5) As a result of several studies focusing on activated carbon production from biomass, more research is needed to determine the feasibility of biomass-based carbon reuse. Since actual wastewater not only contains heavy metals but also contains a complex range of pollutants and most studies have focused solely on activated carbon on a laboratory scale, further research on a broad scale is urgently needed.

4. Conclusion

Lignocellulose biomass-based activated carbon has been reported as a promising commercial carbon substitute alternative. This biomass-based carbon can adsorb various types of heavy metals in wastewater. The benefits of lignocellulose biomass-based carbon over commercial carbon include being relatively affordable, renewable, available, simple to modify, and having a high adsorption capacity. The constituent components of lignocellulose biomass as carbon precursors include lignin, cellulose and hemicellulose. Biomass from plant parts can set aside different types of metals. Aloe vera leaves can remove Pb^{2+} metal in wastewater with 96% effectiveness.

Activated carbon from plant stems in bamboo stems, rice straw, and bagasse can remove metals Cd^{2+}, Pb^{2+}, As^{2+}, Cr^{2+}, Fe^{2+}, Ni^{2+} and Zn^{2+} in various wastewater by 25–97%. Corn cob, the activated carbon from the plant's fruit, can remove up to 95% of Pb^{2+} metal. Activated carbon from grains, such as black persimmons, cherries, olives, palms, and apricot shells, can set aside metals Cd^{2+}, Fe^{2+}, Pb^{2+}, Cu^{2+}, Cr^{2+}, and Ni^{2+} ranging from 55–100%. The effectiveness of removing Cd^{2+}, Ti, Pb^{2+}, Cu^{2+}, Cr^{2+}, and Ni^{2+} metals by activated carbon from banana, watermelon, potato, rice husk and orange peels is 62–99%. The benefits of removing heavy metals with activated carbon made from lignocellulosic biomass are excellent; some biomass from plant parts even excels in commercial carbon. The amount of heavy metals activated carbon can remove depends on several variables, including the adsorbent dose, contact time, solution pH, temperature, initial adsorbate concentration, particle size, and agitation speed. In future research, it is expected that there will be biomass-based activated carbon that has high metal adsorption capacity, lower economic costs, free of pollution, and can applied on a wide scale.

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